Modeling of Mid-Frequency Reverberation in Very Shallow Water

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LONG-TERM GOALS

The long-term goal of this research is development of computationally efficient physics-based methods for modeling of propagation, scattering, and reverberation in shallow waters with complicated spatial and temporal variability of environmental parameters.

OBJECTIVES

A specific objective of this research is to develop a mid-frequency shallow-water reverberation model relevant to specific conditions (1 – 10 kHz, ~20 m water depth, ~ 5 km range) of the ONR Target and Reverberation experiment [1] performed during the spring of 2013 (TREX13). The research is to result in developing computer simulation codes and algorithms for the TREX13 acoustic data analysis based on environmental inputs measured concurrently with the experiment.

A scientific goal of this research is to contribute to involving non-traditional modeling approaches to better understand shallow water propagation and reverberation. This would support the idea expressed in the white paper [1], that a new area of investigation for WPRM (Wave Propagation in Random Media) should be suggested, to be relevant to TREX13 conditions. Particularly, for the chosen mid frequency range and very shallow waters, joint effects of the relatively large bottom penetration and 3D variability of the sediment properties, along with related effects of propagation, 3D refraction, and scattering within the seafloor, should be taken into account. Therefore, an approach is needed that treats heterogeneous stratified sediments as a critical part of the propagation channel (in addition to heterogeneous water column with rough boundaries).

APPROACH

The physics of reverberation in highly heterogeneous shallow water environment can be described using an approach similar to one developed by De Wolf [2] for studying electromagnetic propagation and multiple scattering in a turbulent atmosphere. This approach is well recognized in WPRM community, and called the MFSB-approximation (Multiple-Forward-Single-Backward-scatter). Particularly, the approach is applicable to description of the so-called "backscattering enhancement" effect, known also as "weak localization" and "coherent backscatter" effects. While similar terminology appears frequently in the underwater acoustics literature, such approach for conditions of

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shallow water reverberation has not yet been adequately developed (although experimental observations exist [3]).

An initial discussion of possible using a similar approach to long-range reverberation in a shallow-water waveguide is given in [4]. The main complication in this case (in comparison with previous work) appears because of the multi-path conditions for propagation and related multi-wave local scattering effects in a waveguide, and, more generally, in any stratified (layered) environment. A modified approach outlined recently in [5,6] has addressed the mentioned complication and resulted in derivation of a new simple integral expression for the scattering intensity, which has a factorized integrand comprised of two kernels, the two-way intensity propagator and local volume scattering coefficient. The propagator exploits the local intensity of the propagation field in the background (deterministic) environment and can be calculated using available models, such as PE, normal modes, or ray approximations. The scattering kernel can be specified using available volume scattering models for continuous or discrete heterogeneity of sea-water column and seabed caused by random spatial fluctuations of compressibility and density, or randomly distributed discrete targets, such as bubbles, fish, shells, and others [5-7].

In this research, the approach outlined in [4-6] is proposed to be developed further and applied to specific TREX13 environmental conditions.

WORK COMPLETED

A physics-based model for reverberation in a very shallow water environment has been developed, based on an alternative approach to volume scattering described in [4-6] which significantly simplifies accounting for the effect of stratification and presence of interfaces. The approach also allows considering all relevant volume scattering mechanisms (including heterogeneity of sediments and water column) in a unified model. A basic version of the modeling approach and initial results were presented at the Fall 2013 ASA meeting [8].

Pre-test computer simulations have been performed, with a focus on analysis of various bottom scattering mechanisms, with environmental inputs typical for the chosen TREX13 location, to predict their impact and relative contributions. Such analysis has shown, in particular, that the impact of large shells on reverberation may be substantial at reasonable assumptions, suggesting more effort for collecting such shells during field experiments to provide sufficient ground truth for model/data comparisons. First results of this effort have just appeared [9,10], as well as first results of environmental and acoustic measurements performed during the TREX13 [11-13]. In particular, available by now data on TREX13 shell size analysis shows much higher concentrations (up to 20% in volume [9]) than at SAX04. Estimations based on these data confirm that the contribution of shells (and other discrete scatterers) may be an important mechanism of the TREX13 reverberation.

RESULTS

Based on the developed simplified modeling approach, computer simulations using parameters typical for the TREX13 conditions have been performed. The simulations demonstrate computational capabilities of this approach to provide significantly faster yet reasonably accurate estimations of volume reverberation in complex very shallow water environments. The approach involves two steps in the algorithm of these estimations. The first step is to evaluate the propagator kernel in the waveguide of interest. The double propagator, which in the case of monostatic reverberation corresponds to fourth power of the field's magnitude (being a function of range and depth specified for given shallow water waveguide), then is used as an input, at the second step of the algorithm, to calculate the reverberation intensity as a function of the double propagation time, given the volume scattering kernel defined by the scattering cross section per unit volume for an arbitrary distribution of scatterers. This new modeling approach is therefore more general than, and can be used for verification of, existing reverberation models. For instance, the new model provides estimations of bottom reverberation without calculations of the equivalent surface scattering strength (although may include it as a particular case).

A numerical example for representative (although simplified) TREX13 environments is illustrated in Fig.1. Calculations of the propagation field's magnitude are based on PE-codes [14].

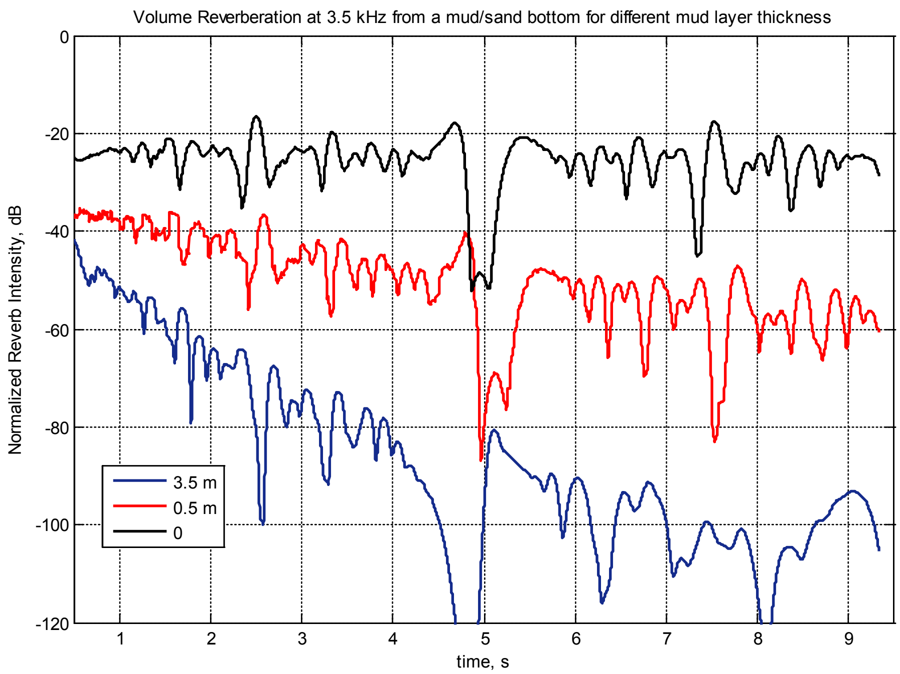

Figure 1. Normalized monostatic reverberation intensity from a mud/sand bottom for different mud layer thickness (0, 0.5, and 2.5 m), water depth 20m, and source depth 19 m.. "Normalized" means "per unit volume scattering strength", i.e. reverberation intensity is calculated assuming the same volume scattering strengths for all scattering mechanisms. This allows then a fast estimation of potential contributions of different mechanisms of scattering with arbitrary strengths and locations.

Further theoretical developments have been performed as well and included a generalization of the mentioned integral expression for the reverberation intensity, where the intensity propagator, following the MFSB-approach, is treated now stochastically and includes multiple forward-scatter effects. Particularly, this generalization allows accounting for effects of backscatter enhancement and forward-scatter scintillations, and therefore incorporates multiple scattering effects into the model of reverberation.

IMPACT/APPLICATIONS

This research is to contribute to further development of shallow water reverberation models and codes. The results of this research will allow testing currently used bottom reverberation codes and their applicability to very shallow water environments at mid frequencies. Particularly, this concerns using CASS/GRAB codes with inputs of GABIM, Geophysical Acoustic Bottom Interaction Model. These models and codes have been widely used in the applied research and development community for predicting and analysis of bottom reverberation at mid frequencies for a wide variety of sea bed types. In particular, they are primary tools used in the Ocean Bottom Characterization Initiative (OBCI).

RELATED PROJECTS

This research is built on results of previous projects funded by ONR-OA [4-7] and other work on shallow water propagation, reverberation and scattering in heterogeneous marine environments. This research assumes a close collaboration with TREX13 PIs, Drs. Todd Hefner, DJ Tang, Kevin Williams, and other TREX13 investigators and researchers working in this field. This research is also closely related to Todd Hefner's effort on theory of high frequency acoustic propagation and scattering in heterogeneous sediments.

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